05 - 61

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
15 November 2001 (15.11.2001)

PCT

(10) International Publication Number
WO 01/85030 A1

(51) International Patent Classification[7]: A61B 6/00, G06T 11/00

(21) International Application Number: PCT/IL01/00201

(22) International Filing Date: 2 March 2001 (02.03.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
136050 9 May 2000 (09.05.2000) IL
09/662,325 14 September 2000 (14.09.2000) US

(71) Applicant *(for all designated States except US)*: PAIEON INC. [US/US]; 747 3rd Avenue, New York, NY 10017-2803 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: EVRON, Rami [IL/IL]; Burla Street 42, 69364 Tel Aviv (IL). ASSIS, Tsuriel [IL/IL]; Ben Zion Street 21/2, 76407 Rehovot (IL). CARMIELI, Ran [IL/IL]; Ha'rotem Street 133, 73615 Rinatia (IL).

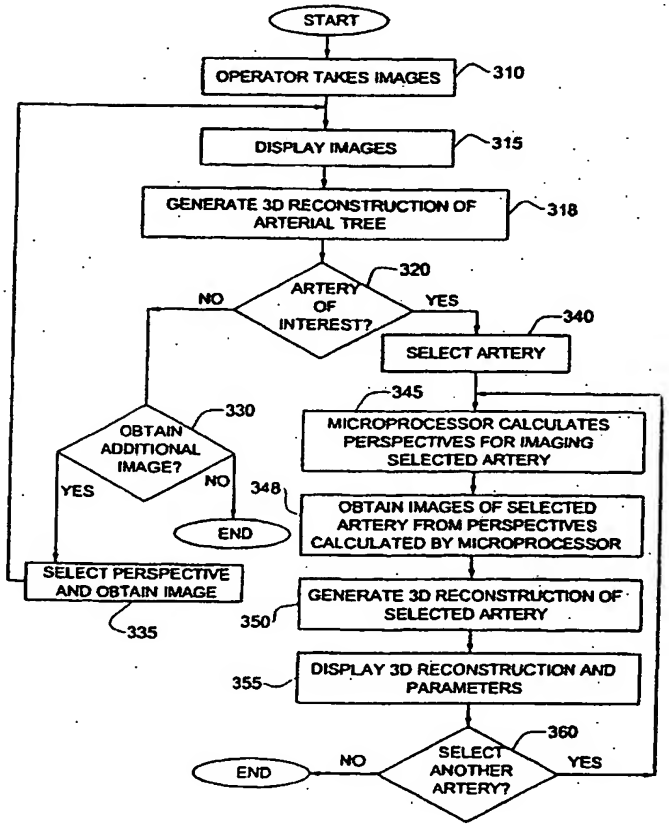
(74) Agent: REINHOLD COHN AND PARTNERS; P.O. Box 4060, 61040 Tel Aviv (IL).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,

[Continued on next page]

(54) Title: SYSTEM AND METHOD FOR THREE-DIMENSIONAL RECONSTRUCTION OF AN ARTERY



(57) Abstract: A method and system for imaging an artery contained in an arterial tree. A microprocessor generates a three-dimensional reconstruction of the arterial tree from two or more angiographic images obtained from different perspectives. The orientation of the axis of the artery in the arterial tree is then determined, and a perspective of the artery perpendicular to the axis of the artery is determined. A three dimensional reconstruction of the artery from angiographic images obtained from the determined perspective is then generated.

WO 01/85030 A1

SYSTEM AND METHOD FOR THREE-DIMENSIONAL RECONSTRUCTION OF AN ARTERY

FIELD OF THE INVENTION

The present invention relates to medical devices, and more specifically to such devices for use in angiography.

BACKGROUND OF THE INVENTION

Stenosis of an artery refers to narrowing of the artery lumen due to plaque formation on the interior wall of the artery. The severity of the stenosis is the fraction of the cross-sectional area of the lumen that is occluded by plaque. Since narrowing is often asymmetrical about the axis of the artery, in order to assess the severity of a stenosis, it is necessary to obtain at least two, and preferably more, images perpendicular to the artery axis from orthogonal perspectives.

In angiography, the arterial lumen is filled with a radio-opaque substance and X-ray images of the arterial tree are obtained from different perspectives. Selection of these perspectives is partly arbitrary and partly a process of trial and error once a stenosis has been observed. However, the overall number of images that can be obtained is limited by time, safety and cost. Usually four to seven projections for the left coronary arterial system and two to four for the right coronary artery are obtained. The operator assesses the severity of the stenosis either on the basis of visual examination of the images or by computer analysis of a single image. Since these projections are in general not perpendicular to the arterial axis, estimation of stenosis severity and its length from these images is usually not accurate.

An artery, for example, a stenotic or aneurotic artery present in any of the obtained angiographic images may be detected by analysis of the images by the microprocessor or by visual examination of the images by the operator. The microprocessor determines the orientation of the axis of the artery in the 3D reconstruction of the arterial tree. The microprocessor then calculates two or more perspectives of the artery perpendicular to the arterial axis. Preferably, two orthogonal perspectives are determined. If images of the selected artery have not already been obtained approximately from the calculated perspectives, the operator obtains angiographic images of the artery from these perspectives and the microprocessor then constructs a 3D reconstruction of the artery from the angiographic images by methods known in the art. The invention thus allows an operator to obtain images of the artery from orthogonal perspectives more rapidly than is possible by prior art methods of trial and error. This allows a smaller radio-opaque dosage to the patient and a reduced exposure of the patient and the operator to X-rays.

The microprocessor may apply meteorological tools to the reconstructed artery. In the case of a stenotic artery, the microprocessor may provide accurate quantitative assessment of the extent and length of the stenosis. The severity of a stenosis may be described quantitatively, for example, by the fraction of the arterial lumen occupied by plaque.

The 3D reconstructed artery may be represented on a display screen using pseudo 3D effects such as directional lighting and shading. In a preferred embodiment, the reconstructed artery is presented as a stereoscopic pair of images to be viewed by the operator using a stereoscopic viewer. The reconstruction may be presented to the operator embedded in the 3D reconstruction of the entire arterial tree. The reconstruction may be manipulated on the screen by the operator, allowing him, for example, to zoom in on a specific region or to rotate the reconstructed artery on the screen to obtain a desired perspective of the stenosis including a perspective showing maximal narrowing or a cross section of the artery.

a generating a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b detecting in the three-dimensional reconstruction of the arterial tree a stenotic artery, the stenotic artery having an axis;

c determining an orientation of the axis of the stenotic artery;

d determining from the three-dimensional reconstruction of the arterial tree at least one perspective of the stenotic artery perpendicular to the axis of the artery;

e generating a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective; and

f analyzing the three-dimensional reconstruction of the artery.

In its fourth aspect, the invention provides a program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for imaging an artery contained in an arterial tree, the artery having an axis, said method steps comprising:

a generating a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b determining an orientation of the axis of the artery in the arterial tree;

c determining from the three-dimensional reconstruction of the arterial tree at least one perspective of the artery perpendicular to the axis of the artery; and

d generating a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective.

In its fifth aspect, the invention provides a computer program product comprising a computer useable medium having computer readable program code

In its seventh aspect, the invention provides a computer program product comprising a computer useable medium having computer readable program code embodied therein for diagnosing stenosis in an arterial tree in an individual the computer program product comprising:

a computer readable program code for causing the computer to generate a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b computer readable program code for causing the computer to detect in the three-dimensional reconstruction of the arterial tree a stenotic artery, the stenotic artery having an axis;

c computer readable program code for causing the computer to determine an orientation of the axis of the stenotic artery;

d computer readable program code for causing the computer to determe from the three-dimensional reconstruction of the arterial tree at least one perspective of the stenotic artery perpendicular to the axis of the artery;

e computer readable program code for causing the computer to generate a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective; and

f computer readable program code for causing the computer to analyze the three-dimensional reconstruction of the artery.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a cross-sectional view and two projections of a stenotic artery;

Fig. 2 is block diagram showing an embodiment of the system of the invention according to one embodiment of the invention; and

Fig. 3 is a flow chart diagram of the process of constructing a three-dimensional reconstruction of a stenotic artery.

230 by means of operator input 250. The microprocessor 230 then brings the X-ray source 200 and the detector 205 into the required orientation by activating a mechanism (not shown) that moves the X-ray source and the detector into the desired orientation relative to the individual's body, as is known in the art.

The microprocessor 230 is programmed to generate a 3D reconstruction of the arterial tree based upon the obtained images. The 3D reconstruction of the arterial tree may be represented on display 255 using pseudo 3D effects such as directional lighting and shading. In a preferred embodiment, the reconstructed tree is presented as a stereoscopic pair of images on display 255 to be viewed by the operator using a stereoscopic viewer. The 3D reconstruction of the arterial tree may be manipulated on the display 255 by the operator by means of operator input 250, allowing him, for example, to zoom in on a specific region or to rotate the reconstruction on the display to obtain a desired perspective.

An artery of interest, for example, a stenotic artery, in an image or in the 3D reconstructed tree is selected by the operator or detected by the microprocessor, for example, by gray level analysis as is known in the art. For example, an image or the reconstructed tree may be displayed on the display 255, and an artery selected by the operator by means of input 250. The microprocessor determines from the 3D reconstruction of the arterial tree the angular orientation of the selected artery. The microprocessor then calculates two or more perspectives perpendicular to the axis of the selected artery. The perspectives preferably include two orthogonal perspectives. If images of the selected artery have not already been obtained approximately from the calculated perspectives, the operator obtains such images. The microprocessor 230 is programmed to reconstruct a 3D image of the selected artery based upon these images. The 3D reconstruction of the artery may be represented on display 255 using pseudo 3D effects such as directional lighting and shading. In a preferred embodiment, the reconstruction is presented as a stereoscopic pair of images on display 255 to be viewed by the operator using a stereoscopic viewer. The reconstruction of the artery may be presented to the operator embedded in the 3D reconstruction of the entire arterial tree.

artery. The reconstructed artery is displayed on the display **255** in step **355** together with parameters describing the artery. For example, for a stenotic artery, the parameters may include the severity and length of the stenosis. The reconstructed artery may be presented to the operator embedded in the 3D reconstruction of the entire arterial tree. The operator may change the display using input **250**, for example, by rotating the reconstructed artery on the display **255** so as to change the scale of the reconstruction of the artery or view the reconstruction from a desired perspective, including an optimal perspective or a cross-section. The operator then decides in step **360** whether he wishes to obtain a 3D reconstruction of another artery of interest in the arterial tree. If so, the process returns to step **340**. If not, additional images are desired, the process terminates.

It will also be understood that the system according to the invention may be a suitably programmed computer. Likewise, the invention contemplates a computer program being readable by a computer for executing the method of the invention. The invention further contemplates a machine-readable memory tangibly embodying a program of instructions executable by the machine for executing the method of the invention.

In the method claims that follow, alphabetic characters used to designate claim steps are provided for convenience only and do not imply any particular order of performing the steps.

7. The system of Claim 3 wherein the microprocessor is configured to display on the display a view of the three-dimensional reconstruction of the artery from a selected perspective, such as a cross sectional perspective.

8. The system of Claim 3 wherein the three-dimensional reconstruction of the artery is displayed on the display embedded in the three-dimensional display of the arterial tree.

9. A method for imaging an artery contained in an arterial tree, the artery having an axis, comprising:

a generating a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b determining an orientation of the axis of the artery in the arterial tree;

c determining from the three-dimensional reconstruction of the arterial tree at least one perspective of the artery perpendicular to the axis of the artery; and

d generating a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective.

10. The method of Claim 9 further comprising a step of displaying on a display any one or more of an angiographic image, the reconstruction of the arterial tree, or the reconstruction of the artery.

11. The method of Claim 9 further comprising a step of making meterological measurements on the reconstruction of the arterial tree or the reconstruction of the artery.

12. The method according to Claim 10 further comprising a step of manipulating an image on the display.

13. The method of Claim 10 further comprising a step of displaying a view of the three-dimensional reconstruction of the arterial tree from a selected perspective.

stenosis includes determining the fraction of the cross-section of maximal narrowing occluded by plaque.

20. A program storage device readable by machine, tangibly embodying a program of instructions executable by the machine to perform method steps for imaging an artery contained in an arterial tree, the artery having an axis, comprising:

a generating a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b determining an orientation of the axis of the artery in the arterial tree;

c determining from the three-dimensional reconstruction of the arterial tree at least one perspective of the artery perpendicular to the axis of the artery; and

d generating a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective.

21. A computer program product comprising a computer useable medium having computer readable program code embodied therein for imaging an artery contained in an arterial tree, the artery having an axis, the computer program product comprising

a computer readable program code for causing the computer to generate a three-dimensional reconstruction of the arterial tree from two or more angiographic images of the arterial tree obtained from different perspectives;

b computer readable program code for causing the computer to determining an orientation of the axis of the artery in the arterial tree;

c computer readable program code for causing the computer to determine from the three-dimensional reconstruction of the arterial tree at least one perspective of the artery perpendicular to the axis of the artery; and

d computer readable program code for causing the computer to determe from the three-dimensional reconstruction of the arterial tree at least one perspective of the stenotic artery perpendicular to the axis of the artery;

e computer readable program code for causing the computer to generate a three dimensional reconstruction of the artery from angiographic images obtained essentially from the determined at least one perspective; and

f computer readable program code for causing the computer to analyze the three-dimensional reconstruction of the artery.

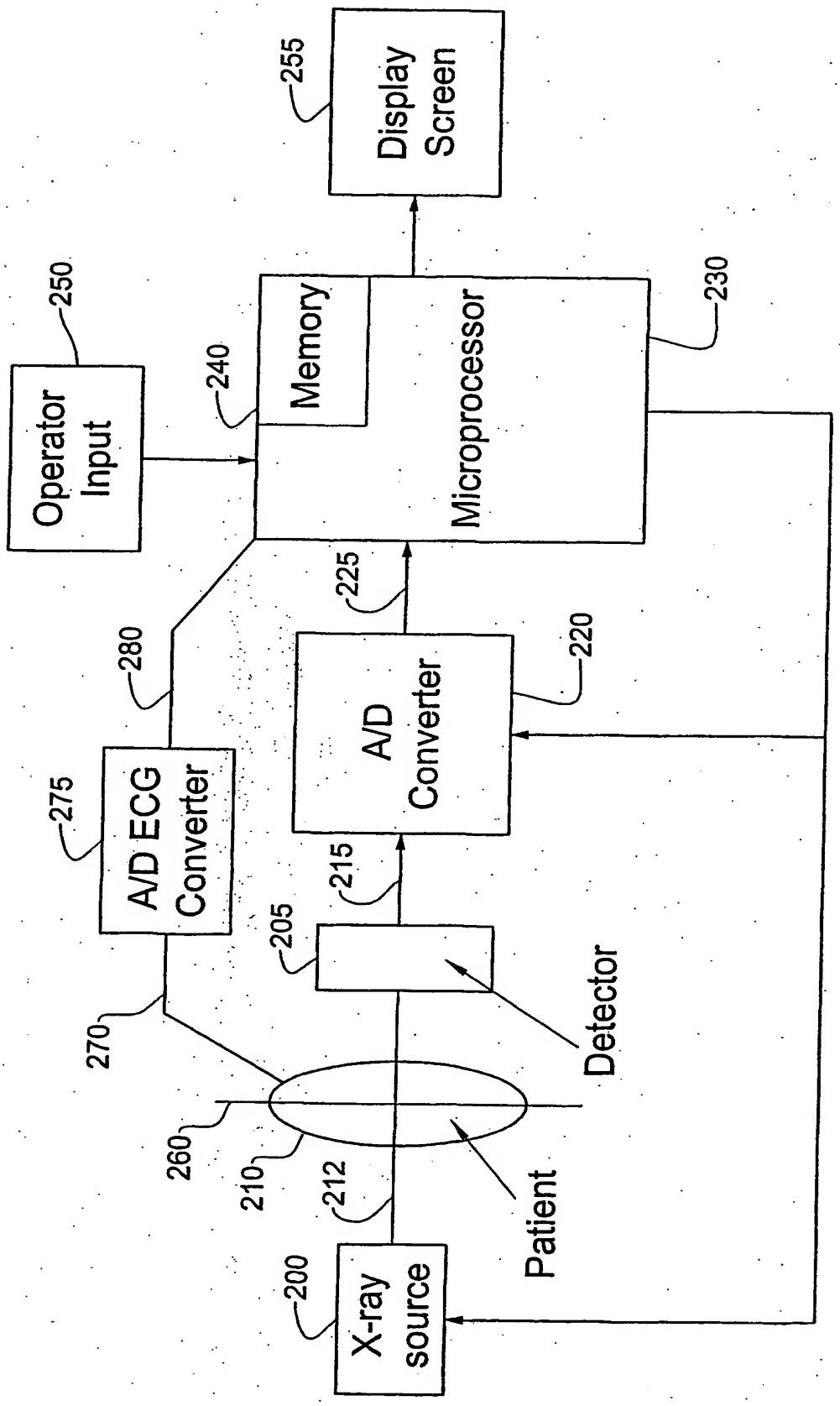

Display Screen
255
Memory
240
Microprocessor
230
Operator Input
250
A/D Converter
220
225
A/D ECG Converter
275
280
Detector
205
215
270
260
210
212
Patient
X-ray source
200

FIG. 2

INTERNATIONAL SEARCH REPORT

International Application No
PCT/IL 01/00201

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61B6/00 G06T11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61B G06T

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 047 080 A (CHEN SHIUH-YUNG JAMES ET AL) 4 April 2000 (2000-04-04)	1-3, 5-16, 20-23
A	column 3, line 31 -column 4, line 6 column 4, line 42 -column 6, line 28 column 20, line 5 - line 31; tables 1-3	17-19
A	US 5 175 773 A (BOULIOU ALAIN ET AL) 29 December 1992 (1992-12-29) column 3, line 53 -column 4, line 37 column 5, line 8 -column 6, line 64; tables 1-3	1,9,16, 20-23

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
19 July 2001	27/07/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Weihs, J

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

In tional Application No
PCT/IL 01/00201

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 6047080 A	04-04-2000	AU 3484997 A	07-01-1998
		EP 0978101 A	09-02-2000
		WO 9749065 A	24-12-1997
US 5175773 A	29-12-1992	FR 2636451 A	16-03-1990
		EP 0434720 A	03-07-1991
		WO 9003010 A	22-03-1990